Accuracy assesments for the VenSpec-U/VeSUV instrument onboard ESA's EnVision mission

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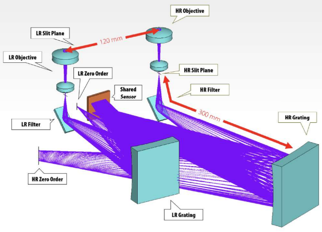
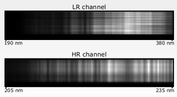
VenSpec-U / VeSUV:

The next ESA mission to Venus, EnVision, aims to study the planet as a whole, including its various constituting parts, their interactions and coupling processes. The payload includes a suite of three spectrometers, the VenSpec suite [1], among which the UV channel called VenSpec-U or VeSUV ("Venus Spectroscopy in UV") [2] will focus on the upper layer of the atmosphere. It aims to monitor sulphured species such as SO_2 and SO, as well as the unidentified UV absorber, and will also observe small scale dynamical patterns such as convection cells or atmospheric waves.

Constituted of two channels called "LR" and "HR", referring respectively to the low and high spectral resolution, the instrument will perform dayside observations of the UV sunlight backscattered by Venus' clouds. Radiance factor spectra using the spectral solar irradiance will then be derived.





SO_2 | SO | UV absorber | Dynamical processes

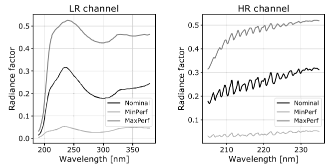
Scientific objectives	SNR (normalised at 220 nm)	Random precision	Effective Spectral Radiometric Accuracy	Absolute Radiometric Accuracy
Measure the SO_2 columns density above the clouds	≥ 200	< 20%	< 50%	-
Measure the SO/SO_2 columns density ratio	≥ 100	< 25%	< 100%	-
Perform long-term monitoring of the UV absorber and clouds	≥ 100	-	-	< 10%

Radiative Transfer Model:

These studies are performed with the Radiative Transfer Model (RTM) updated from the one used for the data analysis of the SPICAV-UV instrument onboard the previous ESA mission Venus Express [3]. The model computes radiance factor spectra from a set of parameters describing the atmospheric characteristics, including VenSpec-U's science objectives:

- **qSO2**: SO_2 mixing ratio at 70 km of altitude
- **img**: imaginary part of the refractive index representing the UV absorber
- **Z2**: cloud-top altitude control point
- **rSO**: SO/SO_2 abundance ratio

Three scenarios are defined in order to estimate variations of the studied performances indicators within an envelope of expected radiometric conditions.



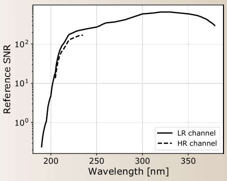
Requirements:

The main science objectives of the instrument have driven the elaboration of a preliminary design based on the requirements (such as spectral ranges, spectral and spatial resolutions) that were formulated with respect to these goals. The compliance of the current design with these requirements, regarding in particular the accuracy of the retrieved science data, should therefore be assessed.

Random errors characterisation

Influence of the Signal-to-Noise Ratio:

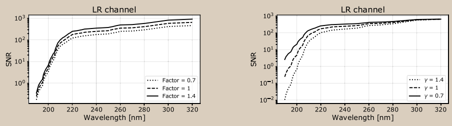
The Signal-to-Noise Ratio (SNR) is used as an optimisation parameter in the Levenberg-Marquardt fitting algorithm involved in the inverse RTM, which leads to an increased reliance on portions of the spectra with higher SNR to find the best estimation of the atmospheric features.



In order to estimate how the uncertainties associated to the retrieved parameters are impacted, variations in the SNR curve are introduced. Two types of SNR alterations are considered:

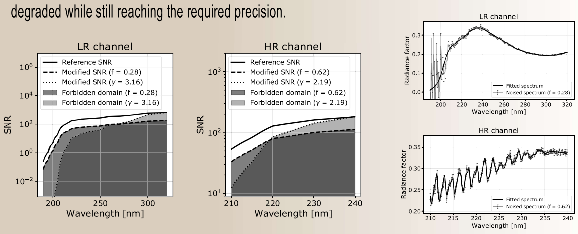
- Multiplicative factor: global attenuation similar for all wavelengths
- Gamma correction: modification of the contrast between short and longer wavelengths without changing the maximal SNR level

$$SNR(\lambda) = SNR_{ref}(\lambda)\cdot f \qquad SNR = \max_{\lambda}(SNR_{ref})\cdot\left(\frac{SNR_{ref}(\lambda)}{\max_{\lambda}(SNR_{ref})}\right)^{\gamma}$$



SNR forbidden domains:

The resulting uncertainties are then retrieved using the inverse RTM for each of these modified SNR spectra and compared to the requirements in order to determine limits until where the SNR can be degraded while still reaching the required precision.



Systematic errors characterisation

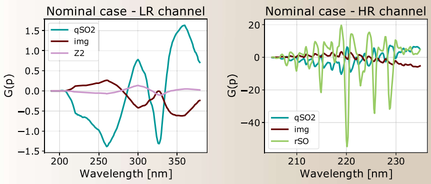
ESRA requirement and gain matrices formalism:

The implemented method is based on the "Effective Spectral Radiometric Accuracy" (ESRA) requirement, previously defined within the framework of the ESA Sentinel missions [4], which evaluate the effects of the similarities between the spectral characteristics of biases and those of the atmospheric components aiming to be detected.

The "Gain matrices" (**G**) involved in this method are representing the linearised inverse RTM, by translating a deviation in radiance factor into a deviation in the estimated atmospheric parameters, and are defined for each parameter of interest. They are computed using the Moore-Penrose pseudo-inverse of the Jacobian matrix associated to the linearised forward RTM (**A**) with a consideration of the SNR influence in the fitting algorithm through a diagonal covariance matrix (**S**). The spectral index is here noted **j** and **k** refers to the index of the retrieved RTM parameter **p**.

$$G = \frac{1}{\Delta\lambda}\cdot\left(A^T\cdot S^{-1}\cdot A\right)^{-1}\cdot\left(A^T\cdot S^{-1}\right)$$

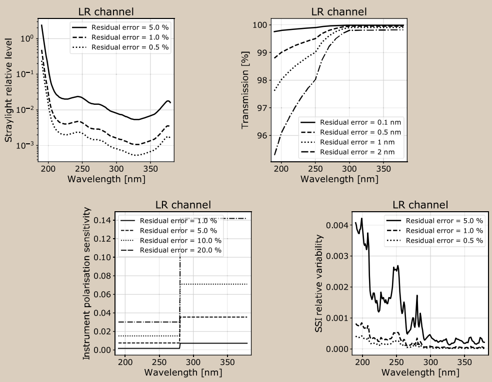
$$\text{with } A_{jk} = \frac{\delta\beta_j}{\delta p_k/p_k} \text{ and } S_{jj} = \left(\frac{\beta_j}{SNR_j}\right)^2$$



Identified biases:

Sources of biases expected to be encountered by VenSpec-U and their impact on the radiance factor spectra have been identified:

- Straylight mainly due to scattering by optical components
- Loss of transmission caused by the progressive deposition of contaminants on the optics
- Sensitivity to the slight polarisation of the observed Venus scene
- Uncertainties on the solar spectral irradiance variability used to derive the radiance factor



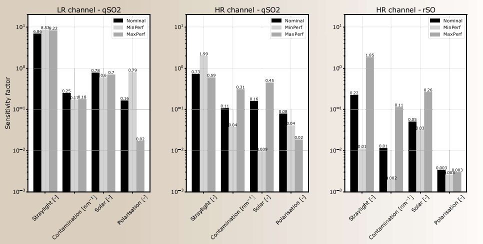
Generic types of biases are also considered to account for non-specific source of biases, described with simple mathematical expressions such as constant additive offset or multiplicative factor. As these biases aims to be corrected, this study is focused on the effects of remaining errors due to the uncertainties of the corrections, and referred to as "residual errors".

ESRA budget allocations :

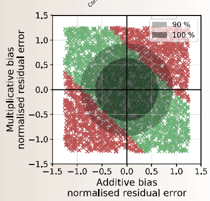
The ESRA contribution of each individual biases can then be computed. A sensitivity factor is defined for each bias using the residual error level necessary to fill the total required ESRA budget, and is used to compare the severities of the various biases. In order to compute the resulting global ESRA, the biases are combined quadratically, as they are considered to be independent.

$$ESRA(p_k) = \Delta\lambda\cdot\sum_j G_{kj}\cdot\left(\beta_{j,\text{measured}} - \beta_{j,\text{true}}\right)$$

The allocation of a maximal residual error for each bias can be made as a first approach by considering their contribution to the total ESRA budget as equivalents.



In order to make these allocations more representative of the instrument, Monte-Carlo simulations can be implemented with realistic estimations of the statistical distribution of residual errors levels for each bias, depending on the calibrations and corrections' expected efficiencies.



References

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